U

TDB-ACC-NO: NB9404605

DISCLOSURE TITLE: Computer-Aided Process Planning

PUBLICATION-DATA: IBM Technical Disclosure Bulletin, April 1994, US

VOLUME NUMBER: 37

ISSUE NUMBER: 4B

PAGE NUMBER: 605 - 608

PUBLICATION-DATE: April 1, 1994 (19940401)

CROSS REFERENCE: 0018-8689-37-4B-605

DISCLOSURE TEXT:

Disclosed is a method of computer-aided process planning for assembly.

- In process planning, a planner decides on an assembly operation sequence and assigns resources to assembly operations, taking account of the cost and cycle time. After the sequence of assembly operations has been determined, some consecutive operations are collected into groups for resources that execute assembly operations. The number of resources is limited, so each resource executes one or more assembly operations. When a production volume is given, an operation time for resources can be calculated. No resource can execute operations that take longer than this time, which is called a cycle time. A planner makes a process in which the operation time of each group of operations is less than the cycle time, and resources are selected for maximum economy by effective utilization of a plant's existing resources.

After obtaining valid combinations of resources, the planner evaluates the processes in which the resource is used by means of a production line simulator and selects a process according to the result of the simulation.

In this method,

1. All possible combinations of operations that satisfy conditions for the grouping of assembly operations are generated.
2. Propositional logic expressions are generated that can manage the order of precedence of operations, the correspondence between operations and resources, and resources themselves. Combinations of operation groups and resources are generated from the expressions by using an ATMS (Assumption-based Truth Maintenance System).
3. A user selects a combination of operations and resources, taking account of cost, work-in-process, and so on.

The selected combination is a good assembly process.

A relational model of a process for process planning can be described as follows:

(N, O, R, res(o), assembly (o), parts(o), time(o,r)).

- N, O, and R are sets of symbols and n, o, and r are members of the sets, respectively. res(o), assembly(o), and parts(o) are functions for mapping between N, O, and R, and time(o,r) is a function for process planning. N is a set of assembly parts and subassemblies. O is a set of assembly operations and R is a set of resources. res(o) returns a list of resources that can execute an operation o. assembly(o) returns a subassembly that is assembled by an operation o and parts(o) returns a list of assembly parts and

subassemblies that are used by an operation o. time(o,r) returns the time taken by a resource r to perform an operation o.
If r cannot
perform the operation o, an infinite value is returned.
The algorithm for grouping assembly operations is as follows:
For all o sub i memberof O, o sub j memberof O, r sub k memberof R, where i ne j,
if o sub i, o sub j, r sub k satisfies
<assembly(o sub i) memberof parts(o sub j)>
labove
<time(o sub i, r sub k)+time(o sub j, r sub k) le cycletime>
and if no o sub l exists such that
<assembly(o sub l)=assembly(o sub j)>
labove
<parts(o sub l)=(parts(o sub i) union parts(o sub j)) - assembly(o sub
i),>
then a symbol o sub m is generated and the following are defined:
<O = O union lbrace o sub m rbrace .>
labove
<'Def'.%%% res(o sub m) = lbrace r sub k rbrace .>
labove
<'Def'.%%% time(o sub m, r sub k) = time(o sub i, r sub k) + time(o sub j, r sub k) .>
labove
<'Def'.%%% assembly(o sub m)=assembly(o sub j) .>
labove
<'Def'.
%%% parts(o sub m)=(parts(o sub i) union parts(o sub j)) - assembly(o sub i) .>
else if o sub l exists but r sub k memberof overlay '/' res(o sub l)
then
<'Def'.%%% res(o sub l) = lbrace r sub k rbrace union res(o sub l)>
labove
<'Def'.%%% time(o sub l, r sub k) = time(o sub i, r sub k) + time(o sub j, r sub k) .>

Given a relational model after grouping operations, we can generate propositional logic expressions for resource assignment as follows.

- Let the number of occurrences of resource r sub j in the relational model be l sub j , and let the number of resources that a plant has be e sub j .

For all o sub i memberof O,
for r sub j memberof R such that time(o sub i, r sub j) lt cycletime
, an expression
assembly(o sub i) larrow parts(o sub i) %%o sub i%% r sub j _k
is generated, where k is a subscript used to distinguish r sub j and
1 le k le l sub j , as described above.
The terms of assembly(o sub
i) and parts(o sub i) denote the values returned by each function, respectively.
Next, for every r sub j such that e sub j lt l sub j, generate all the following expressions that satisfy the following conditions:
False larrow r sub j _ m sub 1 %%r sub j _m sub 2%% ellip r sub j _m sub <e sub j + 1>
where all m sub p and m sub q satisfy the following:
if p lt q, m sub p lt m sub q
1 le m sub p, m sub q le l sub j
1 le p, q le e sub j + 1.

- The generated propositional logic expressions are input to an ATMS. A resource r sub j is regarded as an assumption and a set of assumptions that support a final assembly n sub final is obtained by

an ATMS. Each assumption set in a label assigned to a node n sub final is a set of resources that are used in a process, and we can obtain processes that use the various sets of resources.

- After resources have been assigned to a sequence, we can simulate processes by using a production line simulator and in this way we can determine a good process plan that takes account of cost, work-in-process, utilization of machines, and other relevant factors.

02328414 86926421
Civil aircraft maintenance and support Fault diagnosis from a business perspective
Knotts, Robert M H
Journal of Quality in Maintenance Engineering v5n4 PP: 335-347 1999
CODEN: JQMEFI ISSN: 1355-2511 JRNL CODE: QMGR
DOC TYPE: Periodical; Feature LANGUAGE: English RECORD TYPE: Fulltext
WORD COUNT: 3691
GEOGRAPHIC NAMES: United States; US

DESCRIPTORS: Aircraft industry; Maintenance costs; Expert systems;
Diagnostics
CLASSIFICATION CODES: 8680 (CN=Transportation equipment industry); 9190
(CN=United States); 5250 (CN=Telecommunications systems & Internet
communications)
PRINT MEDIA ID: 46139

ABSTRACT: Aircraft maintenance down times together with maintenance activity durations and associated man-hour expenditure are extremely important factors contributing to two major yardsticks of airline and civil aircraft performance: despatch reliability and direct maintenance costs, and have important cost implications. In maintaining an aircraft there is a need to predict fault diagnosis activities in quantitative terms of time. Traditionally estimating maintenance, in particular fault diagnosis, in terms of time has received scant attention. This paper identifies the need to evaluate all maintenance activity times. In addition, an approach is offered to estimate fault diagnosis activity times using knowledge-based systems. Finally, the paper offers a vision outline in applying the technology and techniques to provide cost-effective and timely fault

diagnosis.

TEXT: Robert M.H. Knotts: Mirce Akademy, Exeter, UK

Introduction

The airline industry is one of the most unique businesses in the world. The complex issues affecting operations management are daunting. People, luggage, freight and aircraft have to be moved over vast distances. Flights, crews, maintenance, cargo and even meals have to be **scheduled** . Fuel, spares, tools, training and publications have to be provisioned. All of these factors have to be considered against a background of timetables coupled with operating and maintenance costs, that is time and money. The pressures of modern business demand rapid diagnosis of a system which experiences a failure. Consequently, high reliance is placed on availability of an expert. However, in the real world of night shifts, sickness and holidays, expertise of the required quality is not always available. In addition, expert services can be lost by change of employment, retirement and death. Add to the problem that while modern equipment is more complex, it is also more reliable. Defects occur less frequently thus causing human expertise to deteriorate through lack of exposure and practice. Complex machinery has diverse technology standards, thus one expert is unlikely to possess all existing system knowledge. An expert system, developed to capture system knowledge, expertise and experience, will produce more accurate and consistent results than its human counterpart. The system will also make expertise available to many users, offering expert knowledge to guide and direct less skilled maintenance staff.

This paper will focus on issues of time and money from the point of view of fault diagnosis associated with maintenance and support

activities. As in all environments of maintenance and support, time is money.

Airline industry - in-service aircraft cost focus

Two major yardsticks of airline and civil aircraft performance with important cost implications are despatch reliability (DR) and direct maintenance costs (DMC):

(1) Despatch reliability (DR). The percentage of revenue departures which do not incur a delay or cancellation as a result of technical problems (ATA, IATA and ICCAIA, 1992). Technical delays occur when the malfunctioning of equipment and related checking and required corrective action causes the aircraft's departure to be delayed by more that a specified time after the **scheduled** departure time. Delays are deemed to have occurred if an originating flight departs later than the **scheduled** departure time, a turn round flight remains on the ground longer than the allowable ground time or if the aircraft is released late from maintenance. A cancellation occurs if a flight is cancelled after being delayed. Airlines frequently seek DR guarantees where the aircraft manufacturer is faced with financial penalties if DR levels are not achieved.

(2) Direct maintenance costs (DMCs). The labour and material costs directly expended in performing maintenance of an aircraft or related equipment (ATA, IATA and ICCAIA, 1992). The costs do not include the labour and material expenditures which contribute to activities such as administration, supervision, tooling, test equipment, facilities, record keeping etc. Over a 30-year aircraft life DMCs make a significant contribution to an aircraft's cost of ownership. Airlines also seek maintenance cost guarantees, where the aircraft manufacturer incurs financial penalties if DMCs exceed agreed specified levels.

Other important criteria are servicing turnaround time, system and
equipment reliability and **maintenance** down time. The increasing
complexity of systems places demands on system maintenance to contain and
reduce maintenance down times. Every system and associated component has a
function to perform. The primary objective of maintenance is to keep the
system serviceable, and thus available to perform that function. When the
system fails the maintenance technician has to diagnose the fault and
rectify the failure as quickly as possible to return it to a serviceable
condition. While test procedures and maintenance manuals contain
recommended steps for detecting and rectifying defects, their use alone
does not guarantee success in timely diagnosis and repair.

Airlines operate in a very competitive environment, particularly with the
advent of deregulation and reduced government ownership. Moreover, other
modes of transport may offer competitive pressures. In Europe and Japan
high speed rail links over distances of 200-300 miles can be attractive to
travellers in terms of time, convenience, comfort and cost. Subsidised
operations enjoyed by some airlines place others at a financial
disadvantage. Airlines seek to minimise operating costs, one important area
being that of maintenance where the ingredients are labour and material.
They also seek aircraft with high levels of despatch reliability and a full
understanding of the consequences of it not being achieved, together with
full visibility of the consequential down time (Fielding, 1979). Airlines
talk in terms of available seat kilometres flown, aircraft utilisation,
fuel efficiency, punctuality and cancellations.

Aircraft design determines in-service DR and maintenance costs. Thus
airlines look to aircraft manufacturers for high RMS standards and seek

agreements which place significant levels of aircraft in-service economic risks with the manufacturer. Guarantees covering DR, maintenance and parts cost limitations together with extended warranties are typical of contractual obligations sought.

Scheduled flights can be subject to a number of delays:

- air traffic congestion;
- weather;
- flight crew problems;
- passenger problems;
- ramp handling problems;
- technical problems.

Figure 1 quantifies the factors contributing to delays suffered by Boeing 747s in service with a long haul airline (Confidential source A, 1994); technical delays and cancellations account for about 20 per cent of the total. The figure also gives typical delay costs per minute by aircraft type (Confidential source B, 1994).

Tangible delay costs are attributable to (Sisk, 1993):

- spares;
- airport fees;
- concessionary aircraft costs;
- labour charges;
- ATC costs;
- rescheduling costs;
- passenger costs - food, accommodation, transport, payoffs.

Non-tangible costs include (Sisk, 1993): passenger dissatisfaction; opportunity for competitors; negative publicity.

It is not surprising that DR and ownership costs are important

factors in an airline's decision-making process when selecting new aircraft. A typical ranked list of an airline's decision criteria (Confidential source B, 1994) is given below:

(1) Fitness for purpose coveting performance, range, capacity and comfort.

(2) DR and MTBUR.

(3) Cost of ownership - acquisition, operating and maintenance costs.

(4) Manufacturer's reputation covering quality and product support.

(5) Manufacturing lead times and production rates.

Aircraft cost of ownership and equipment "no fault found" costs

Aircraft cost of ownership has to be considered from two aspects: costs born by the aircraft manufacturer and vendors and costs faced by the aircraft operator. Costs associated with all life cycle stages up to, and including, production are faced by the manufacturer and vendors who also face costs incurred against contractual obligations, such as warranties, guarantees (e.g. against such factors as availability and maximum maintenance cost levels) and relayed penalties during the in-service phase.
The aircraft operator is responsible for costs covering acquisition (purchase or lease), operation together with maintenance and support. In addition, the operator can incur costs where the product is not available for use, that is "down time" costs. The situation is summarised in Figure 2.

The increasing complexity of systems and technology adds to the difficulty of effective and timely fault diagnosis, thus contributing to the problems of system maintainability. Moreover, ineffective fault diagnosis can be

expensive in terms of down time and cost, with "no fault found (NFF)" situations contributing significantly to maintenance costs. Current system designs experience a 40 per cent, or higher, equipment false removal rate as a result of ambiguous and labour intensive test procedures (Sheppard and Simpsom, 1990). Avionics and electrical **unscheduled** maintenance accounts for 18 per cent of a civil aircraft's DMC, 40 per cent of related equipment removals are classified as NFF (Boeing Airplane Group, 1980). In 1992 an audit of component removals highlighted an average of 8,000 items removed from British Airways' fleet per month. A total of 14 per cent of components, across all workshops, were found to have NFF. Certain avionics equipment experienced 30 per cent NFF. Financially, taking into account direct and indirect costs, this equated to an annual NFF expenditure totalling Pounds 20 million (Gatland and Trevor, 1993).

Aircraft maintenance

Aircraft maintenance activities form an essential part of airworthiness. The common objective of aircraft maintenance, civil or military, is to provide a fully serviceable aircraft when it is required by the operator at minimum cost. Maintenance are those actions required for restoring an item to a serviceable condition, including servicing, repair, modification, overhaul, inspection and determination of condition.

Maintenance can be categorised as:
- Corrective maintenance. All actions performed as a result of failure to restore an item to a satisfactory condition by providing correction of a known or suspect malfunction and/or defect (Civil Aviation Authority, 1992). Corrective maintenance can include any or all of the following steps: defect location, defect isolation, disassembly, replacement,

reassembly, alignment/adjustment, and testing. This type of maintenance is known as **unscheduled** maintenance.

- Preventive maintenance. All actions performed at defined intervals to retain an item in a serviceable condition by systematic inspection, detection, replacement of wear out items, adjustment, calibration, cleaning etc. (Civil Aviation Authority, 1992). This type of maintenance is carried out at prescribed points in an aircraft's and equipment's life and is termed **scheduled** maintenance.

The United Kingdom Civil Aviation Authority (CAA) (Association Europeene des Constructeurs de Materiel Aerospatial, 1992) recognises three primary maintenance processes:

(1) Hard time. A preventive process in which deterioration of a component is limited to an acceptable level by maintenance actions carried out at specific times (e.g. calendar time, flying hours, number of cycles or landings). The related maintenance includes servicing, overhaul, replacement in accordance with instructions in appropriate manuals. The components concerned are replaced or restored to a condition such that they can be released for service for a further specified period.

(2) On condition. Another preventive process but one where a component is inspected or tested at specified periods. The inspection/test will determine whether it can continue in service or require servicing actions. The prime purpose of this process is to ensure that a component is removed before experiencing in-service failure.

(3) Condition monitoring. This is not a preventive process but one where information on components gained from in-service experience is continuously collected, analysed and interpreted as a means of implementing

corrective procedures.

The processes are summarised in Figure 3.

Focus on time

To understand maintenance costs fully it is necessary to understand the constituent elements of maintenance in terms of time. Figure 4 gives a breakdown of time elements covering the constituent parts of aircraft maintenance activities. The breakdown, adapted from a time relationship chart produced by AECMA (Association Europeene des Constructeurs des Materiel Aerospatial, 1989), can be used to show designers areas where they can influence related activity times. The breakdown in Figure 4 is still the process of development and serves only as an indication of its potential. To illustrate the concept the figure concentrates on outlining times associated with corrective maintenance, in particular looking at access time. The main focus in Figure 4 is to show that fastener removal times depend on factors such as the number and type of fasteners, access and manipulation space, a technician's reach and field of view and the accompanying tool space envelope. In corrective maintenance there is a need to detail fully component disassembly and reassembly sequences as part of the related time estimating analysis. Predicting defect location time is extremely difficult and depends on the effectiveness of diagnostics aids as outlined in Figure 4.

Fault diagnosis

Historically the design of integrated systems has been carried out in isolation to the development of maintenance procedures. Specification of rectification activities resulted from work in identifying

potential failures which led to equipment malfunction. This approach had a number of deficiencies:

- Corrective actions/procedures stemmed only from identification of system malfunctions.

- Difficulties in recording the experience and expertise of system specialists.

- Difficulties in retaining and exploiting expert knowledge.

- Cumbersome and inefficient diagnostic aids leaving maintenance personnel to either remember test procedures or otherwise transport system documentation to the fault diagnosis and rectification site.

More recently system design and development accepted the need to consider future in-service maintenance. Manual fault diagnostic aids and low-level maintenance technician expertise were suited for simple systems. However, as system complexity increased greater levels of maintenance technician expertise were needed, together with the sophistication of test equipment, which started to exceed the technician's capabilities (Esker et al., 1990). The situation brought about development of a number of techniques to assist the technician, including built-in test equipment (BITE), automatic test equipment (ATE) and electronic manuals. BITE was incorporated in a design to continuously test system functionality while the system was operating. It is important to note that BITE was not originally intended to isolate faults, only to detect faults (Esker et al., 1990). It is also important to note that the skills demanded of a maintenance technician far exceed just fault detection. In addition to detecting faults, they involve testing, diagnosing and rectification which are knowledge-intensive and experience-based activities (Grigouri and Willey, 1987). Problems

are solved by applying test and maintenance procedures, coupled with how a system works and, at times, intuition. Knowledge applied has been acquired by study, investigation, observation and experience. With years of experience a system expert gains (Grigouri and Willey, 1987): a detailed understanding of system functionality; an intuitive behaviour of system behaviour when certain sub system(s) fail; and an understanding of the relationships between symptoms, failed subsystem(s) and symptom interaction.

Research has shown that when confronted with a problem a system expert analyses the problem in a disciplined and structured manner, rather than randomly trying possible alternatives in the hope of finding a solution (Grigouri and Willey, 1987). Hypotheses are established, based on symptoms, which are then tested and linked to potential corrective actions. However, it takes time to develop an expert (Hanekom, 1992), as shown in Figure 5.

From a diagnostic point of view knowledge can be classified as shallow and deep. Shallow knowledge includes basic system knowledge covering first order functionality and interconnectivity. Deep knowledge, a combination of system knowledge covering higher order functionality and diagnostic expertise, is accumulated over time and with experience.

The pressures of modern business demand rapid diagnosis and rectification of a system which experiences a malfunction. However, diagnosing and isolating faults in a complex system requires detailed analysis of systems characteristics which takes time. Associated lack of expertise, low skill levels, poor system knowledge, ineffective failure definition together with poor maintenance and diagnostic support tools demand a knowledge-

based diagnostic tool, not only to aid timely fault diagnosis but also to provide a capability of predicting diagnosis times. Figure 6 gives a breakdown of time and activity relationships focusing on fault diagnosis as a subset of corrective maintenance down time (Knotts, 1995a).

Ineffective fault diagnosis can be attributed to a number of factors. First, high reliability and integrated systems where infrequently occurring complex failures limit a technician's exposure to a problem, thus inhibiting the learning curve. Second, unavailability of test resources such as experienced technicians, meaningful manuals, effective fault diagnosis aids and efficient BIT and external test equipment. Third, poor understanding of system configuration. One European airline (Confidential source B, 1993) estimates that 60 per cent of **unscheduled** rectification down time is attributed to poor configuration management reference material.

Fault diagnosis, rectification and testing follows the format illustrated in Figure 7 (Knotts, 1995b).

Time covering access, defect rectification (adjustment, repair or replace), test and close up can be predicted, either from in-service experience or from predictive techniques using time standards such as method time measurement (MTM). However, little, if any, attention seems to have been given to producing time prediction techniques covering fault diagnosis and isolation. There is no reason why the time needed to diagnose and isolate a fault cannot be predicted if a structured and disciplined expert approach is adopted. Logical test procedures, developed by a system expert, can be broken down and subjected to timing analysis, either by timing test

procedure activities against an actual system or by time standard analysis.

In isolating a fault in a complex system an expert develops a search strategy based on knowledge, experience and reasoning logic. Such a strategy will direct an immediate course of action based on success probability from past experience, moving to lesser probability areas if the fault is not immediately isolated. Resolution of unusual defects adds to the expert's knowledge and defect probability data set for future diagnosis work.

If this approach is developed for an electronic expert fault isolation strategies can form part of the direction offered by such a tool and can be used to direct less skilled maintenance staff in effective and timely fault diagnosis. In addition, if the electronic expert is used to time test procedure and fault isolation activities the fault diagnosis time prediction and probability data set can be fine tuned against in-service experience. The human expert's electronic counterpart can expand its knowledge base of frequency and type of defects to allow amendment of future search strategies, coupled with predicted times against each defect probability.

Fault diagnosis vision

Traditionally maintenance technicians rely heavily, if not totally, on technical publications for all reference information covering configuration details, functionality descriptions, fault diagnosis procedures and test procedures. On isolating a fault reference is made to maintenance manuals for procedures on component adjustment or removal, having first consulted a zonal reference document to identify the **location** of the relevant **component** and related access panel. The illustrated parts

catalogue is used to identify part numbers and formal component descriptions for use in ordering replacement spares and related expendables. The maintenance manuals and test procedures provide reference information for fitting and testing of a serviceable component. Their cumbersome nature and inefficiency in fault diagnosis restrict portability and often force maintenance technicians to try and remember test procedures and related maintenance activities, contributing to unstructured fault finding and excessive down time. Related equipment removals may well be classified as NFF, adding unacceptable expenditure to the cost of maintenance. Fault diagnosis also relies on the technician's experience, knowledge and reasoning skills to develop a fault isolation strategy, while extreme difficulty is experienced in forecasting the diagnosis time. An expert is not always available. Moreover, feedback and update of procedures, manuals and all related publications rely on manual effort. A system is envisaged where all reference material is centrally and electronically stored, which directs fault diagnosis isolation, thus assisting technicians lacking system expertise, and which allows prediction and update of diagnosis times. In short a rugged PC, offering access to all relevant data and information, replaces numerous publications and serves as an electronic toolkit for use by technicians at the work site. A vision of such a system is given below:

- Expert knowledge is collected and modelled in a central system to provide a knowledge-based fault diagnosis system.

- Reference functional, configuration, maintenance and test procedure data and information are contained electronically in the expert system in

textual, graphical and diagrammatic formats.

- The knowledge-based fault diagnosis model and reference information is downloaded to a rugged PC.

- The PC is issued to the maintenance technician.

- The knowledge-based fault diagnosis system provides a strategy to direct the maintenance technician in isolating the fault, at the same time offering relevant reference information as required or as requested.
- The maintenance technician's diagnosis activities are timed by the PC to generate a data set of diagnosis prediction times.

- The PC system has the facility to incorporate new symptoms and related diagnostic procedures in temporary memory for subsequent human expert analysis and validation prior to updating of the central system.

- Fault diagnosis search strategies, coupled with forecast success probability, are modified in the system with in-service experience.

The situation is illustrated in Figure 8.

Conclusions

Modern business pressures demand rapid diagnosis and rectification of system malfunctions, placing high reliance on system experts. Such expertise is not always available. Moreover, the cumbersome nature of maintenance publications, together with their inefficiency and lack of effectiveness as diagnostic aids leads to unstructured and illogical fault diagnosis. Related equipment removals frequently result in NFF situations, adding unacceptable expenditure to the cost of maintenance. An expert system, developed to capture system knowledge, expertise and experience, will produce more accurate and consistent results than its human

counterpart. The system will also make expertise available to many users, offering expert knowledge to guide and direct less skilled maintenance staff. In addition, such a system offers an opportunity to predict fault diagnosis times, thus contributing to the overall efficiency of aircraft maintenance management and providing cost-effective and timely fault diagnosis.

References

1. Association Europeenne des Constructeurs de Materiel Aerospatial (1989), Discussion Paper on the Subject "Prediction of Maintenance Costs", March.

2. ATA, IATA and ICCAIA (1992), Airline Industry Standard World Airlines Technical Glossary - Fourteenth Edition, ATA, IATA and ICCAIA, November.

3. Boeing Airplane Group (1980), Boeing Cost Methodology.

4. Civil Aviation Authority (1992), CAP 418 Condition Monitored Maintenance: An Explanatory Handbook.

5. Confidential source A (1994).

6. Confidential source B (1994).

7. Esker, E.A., Simpson, W.R. and Sheppard, J.W. (1990), Air Embedded Maintenance Sub System, ARINC Research Corporation, September.

8. Fielding, J.P. (1979), "A transport aircraft despatch reliability formula", Second National Reliability Conference.

9. Gatland, I. and Trevor, A. (1993), "No fault found", British Airways Engineering, April.

10. Grigouri, M.M. and Willey, C.T. (1987), Expert Systems for Maintenance Engineering, Not Known, Circa 1987.

11. Hanekom, P.P.A. (1992), A Knowledge Representation Concept For

Integrating Diagnostic Knowledge, XCEL Engineering and Management (PTY)
Ltd, South Africa, May.

12. Knotts, R.M.H. (1995a), "Airline maintenance and costs", lecture to MSc
Course, University of Bristol, February.

13. Knotts, R.M.H. (1995b), Integrated Logistics Support and Military
Aircraft, presentation to Swedish Ministry of Defence.

14. Sheppard, J.W. and Simpsom, W.R. (1990), Integrated Diagnosis - A
Hierarchical Approach, ARINC Research Corporation, September.

15. Sisk, L. (Manager, Service Engineering Team, Aer Lingus) (1993),
"Analysing the value of maintenance in terms of despatch reliability", Cost
Effectiveness Maintenance Conference, 26-27 April.

Caption: Figure 1.; Aircraft delays and consequential costs; Figure 2.;
Civil aircraft cost of ownership; Figure 3.; Summary of processes; Figure
4.; Civil aircraft maintenance-time relationships; Figure 5.; System and
knowledge level; Figure 6.; Fault diagnosis - time and activity
relationship; Figure 7.; Fault diagnosis and time prediction; Figure 8.;
Fault diagnosis vision